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FIG. 1 is a schematic diagram of a cross-section of a substrate 12(30). The substrate contains a mixture of particles 32 and 34. A layer of particles 38 is shown on the top surface of the substrate.

An iontophoretic structure for medical devices is provided that uses controlled electrical current derived from two dissimilar galvanic materials to drive oligodynamic metal ions (38) into solution to kill bacteria on and near the device to which the structure is affixed. In one embodiment, a first galvanic material (32) separated from a second galvanic material (34) by a resistive material (30) produces an anti-bacterial current flow when placed in contact with an electrolytic fluid. In another embodiment, a cylindrical elastomeric catheter (10) incorporates a first and a second galvanic material separated by a resistive material which controls a current flow between the galvanic materials when the catheter is immersed in an electrolytic fluid. The galvanic materials can be dissimilar metal powders embedded in a conductive polymer substrate that forms an iontophoretic composite material, or dissimilar metals arranged in layers (76, 80) separated by a resistive layer (78). In yet another embodiment, the iontophoretic composite material is configured as an infection control sleeve (60) that covers a portion of an ordinary catheter or cannula. Methods of protecting implantable medical devices and body structures with the iontophoretic structures are also provided.

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IONTOPHORETIC STRUCTURE FOR MEDICAL DEVICESFIELD OF THE INVENTION

The invention relates to oligodynamic iontophoresis, and more particularly to an electrically conductive structure for medical devices that reduces or eliminates bacterial infection by killing bacteria with controlled oligodynamic iontophoresis.

BACKGROUND OF THE INVENTION

Oligodynamic metals, such as silver, are effective in minute quantities as bacteriostats and bactericides. The most active form of these oligodynamic metals is as ions in solution. While the precise nature of the bactericidal effect is unknown, it is believed to involve altering the function of the cell membrane or linking to the cell's DNA to disrupt cell function. The bactericidal action is effective against a broad spectrum of bacteria, including all of the common strains which cause infection. When these metals are used in the minute concentrations required to kill or stem the growth of bacteria, they do not have any detrimental effect on normal mammalian cells.

Silver is used routinely in antibacterial salves, such as silver sulfadiazine, and has also been used in clinical trials to coat gauze for burn dressings. Medical devices, such as catheters, with silver impregnated in a soluble collagen or polymer coating are also known. After these catheters are placed, the coating slowly dissolves and the silver is released over time into the environment. The infection rates with these products are reported to be two to four times lower than standard catheters.

One catheter that uses silver as an antibacterial agent has had only limited success because the device, consisting of a silver impregnated collagen cuff which is inserted just below the skin, is difficult to place correctly. The cuff

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is also expensive, increasing the cost of a central venous catheter almost three-fold. Other catheters for reducing infection rates use well known approaches, most of them varying only in the type and solubility of the silver or silver-alloy coating.

Many of the prior art catheters that use oligodynamic metals as bacteriostats fail to adequately prevent infection for one or more of the following reasons: 1) Silver released from soluble coatings is not always in the same charge state and often is not charged at all, therefore its bactericidal potential is not optimized; 2) With soluble-coated catheters, once the coating dissolves, usually over about two weeks there is no further antibacterial protection; 3) A non-soluble silver, silver alloy or silver-oxide coating can prevent colonization of the catheter to a limited extent, but the oligodynamic metal is not released into the surrounding fluid or tissue; 4) Due to the substantial change in the catheter placement procedure, the use of these catheters requires additional personnel training; and 5) Although infection can enter the body through either the interior or the exterior of the catheter, not all catheters provide both interior and exterior protection. Furthermore, despite the capability of silver-alloy coated devices to produce a two to four fold reduction in bacterial colonization, their high cost greatly detracts from their modest capabilities.

Research from the 1970's onward has been directed toward improving the antibacterial effects of oligodynamic metals by electrically injecting the metal ions into solution. This process, known as oligodynamic iontophoresis, is capable of reducing bacterial colonization fifteen to one-hundred fold. Iontophoresis describes the movement of ions in a conductive fluid under the influence of low-strength electric fields, and in this context refers to the forcing of ions into a conductive fluid environment using minute electric currents. For example, if two electrodes made of a metal, such as silver, are introduced into a conductive medium, such as

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5 saline, blood or urine, and an electrical potential is applied across the electrodes, silver ions are driven into solution creating an enhanced bactericidal effect. The current required to safely drive a sufficient amount of silver ions into solution to control infection is in the range of 1 to 400 microAmperes. This current range does not cause localized cell necrosis and it is below the sensory or pain threshold.

10 Despite its great potential, the oligodynamic iontophoresis phenomenon has found limited use in conjunction with medical devices, although urological or Foley catheters have progressed to animal experiments. With respect to Foley catheters, researchers have identified several deficiencies in prior art devices. Foremost is that the electrodes used
15 to force ions into solution wear out, or corrode, at the interface between air and the conductive medium. This problem probably also arises in blood or saline environments as well as urine. Other significant drawbacks with prior art iontophoretic devices include bulky, current-controlled power
20 sources required for driving the electrodes; electrode configurations that do not protect both the outside and the inside of the catheter; and manufacturing processes that are labor intensive.

25 An example of an infection control catheter that uses separate electrodes on the catheter and an external power supply to drive ions into solution is U.S. Patent No. 4,411,648 to Davis. Other prior art oligodynamic iontophoresis devices do not use external power supplies. For example, U.S. Patent No. 4,886,505 to Haynes, teaches
30 placing two metals in direct physical contact to produce electrical currents. The currents produced, however, are likely to be too large to be safely used and possibly will alter the pH of the environment. In German Patent Document DE 3,830,359, two dissimilar metal powders not in electrical
35 contact with each other are embedded in a nonconductive catheter material, such as electrically insulating polymers.

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Because of the separation of dissimilar metals by an insulator, it is not likely that there is any iontophoresis effect in this device as a result of a potential being created by the dissimilar metals, except for the possibility of when a biofilm forms on the catheter surface to complete the circuit. Were an electrical circuit to be formed in this manner, the current density would not be regulated or predictable, and the current produced therefore could be either too high to be safe or too low to be effective.

An oligodynamic iontophoresis catheter which uses the properties of metals to generate a current and to form an ion barrier for killing bacteria at a localized body entry is disclosed in U.S. Patent No. 4,569,673 to Tesi. Tesi teaches placing a strip of an oligodynamic metal on a nonconductive substrate. The oligodynamic metal acts as a sacrificial galvanic anode and gives off ions when placed in conductive contact with a dissimilar metal by placing the catheter in an electrolytic solution. Because the conductivity and pH of urine, for example, varies over time within the same person, as well as from individual to individual, it would be extremely difficult to achieve a specific current density at a given time with any precision or predictability. Additionally, the Tesi device only provides localized infection control.

Thus, none of these devices fulfill the promise held out by oligodynamic iontophoresis for reducing infection in long-term indwelling medical devices.

SUMMARY OF THE INVENTION

The present invention provides an iontophoretic structure for a medical device that reduces the risk of infection associated with prolonged medical device implantation in the body. Specifically, the invention is directed toward meeting performance goals of general antibacterial effectiveness; minimal electrode corrosion; precise control of electrical current; portability of the

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current source; and ease of manufacture. These performance requirements can be readily addressed by a number of embodiments in which a controlled electrical current drives oligodynamic metal ions into solution to kill bacteria on and near the iontophoretic structure.

In one embodiment, an iontophoretic structure for a medical device includes a first and second galvanic material separated by a resistive material, which when placed in contact with an electrolytic solution creates a current flow which injects anti-bacterial oligodynamic metal ions into the solution.

In another embodiment, an elastomer incorporates a first and a second galvanic material separated by resistive material which controls a current flow between the galvanic materials when the elastomer is immersed in an electrolytic fluid. The first and second galvanic materials can be metal powders in a conductive polymer that forms a composite material which may be dip-coated over an existing catheter or extruded to form the catheter itself. Alternatively, the galvanic materials can be configured in layered structures, wherein each metal layer is separated from the other by a resistive layer. The layered structures can be placed on surfaces of the catheter where antibacterial action is desired.

In another embodiment, two dissimilar metal powders embedded in a conductive polymer substrate create an infection control sleeve that covers an ordinary catheter. When the sleeve is placed in an electrolytic fluid to complete a circuit between the metal powders, metal ions are driven into solution where they have an antibacterial effect. This embodiment is also useful as a catheter introducer sheath.

In yet another embodiment, a method is provided for giving an implantable medical device antibacterial properties by placing an iontophoretic structure on its surface prior to implantation. The iontophoretic structure can be either

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a coating including two dissimilar metal powders in a conductive polymer substrate, or a layered structure having two dissimilar metal layers separated by a conductive layer.

5 In still another embodiment, a method is provided for protecting a natural body structure with an iontophoretic structure comprising two dissimilar metal powders in a conductive base material. The iontophoretic structure is painted onto the body structure when the base material is in a softened or uncured state. The base material is then
10 allowed to harden or cure.

DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

15 Fig. 1 is a perspective view of an iontophoresis catheter incorporating a composite material comprising metal powders in a conductive elastomeric matrix;

Fig. 2 is a partial sectional view of the iontophoresis catheter of Fig. 1;

20 Fig. 3 is a depiction of the iontophoresis effect created by the composite material in the catheter of Fig. 1;

Fig. 4 is a perspective view of a pacing lead coated with the composite material of Fig. 1;

25 Fig. 5 is a perspective view of an artificial hip joint partially coated with the composite material of Fig. 1;

Fig. 6A is a perspective view of an infusion pump coated with the composite material of Fig. 1;

Fig. 6B is a perspective view of a tooth coated with the composite material of Fig. 1;

30 Fig. 7 is a perspective view of a catheter with an iontophoresis infection control sheath;

Fig. 8 is a perspective view of a catheter with an iontophoresis infection control introducer sheath;

35 Fig. 9 is a perspective view of an iontophoresis catheter having a plurality of layered electrodes;

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Fig. 10 is a perspective view of an alternative embodiment of an iontophoresis catheter having a plurality of layered electrodes arranged in strips; and

Fig. 11 is a partial sectional view of the iontophoresis catheter of Fig. 10.

DETAILED DESCRIPTION OF THE INVENTION

Iontophoretic structures in accordance with the invention may be divided into two categories: a composite material used to coat a medical device, or a plurality of discrete layered electrodes placed on the medical device, both of which categories are disclosed hereinbelow. The medical device can be a short-term, long-term, or permanent implant and includes such devices as: urinary catheters, vascular access catheters and introducer sheaths, fluid introduction tubing and fittings such as intra-venous tubing, urinary drainage bags and tubing, chest drainage tubes, infusion pumps, pacing leads, tracheotomy tubes, ventilation tubes, prosthetic joints, heart valves, wound dressings, orthopedic pins or plates, or any other medical device used in an environment or application where anti-bacterial properties are a consideration. However, because urinary catheters are an especially attractive application for the iontophoretic structures, the ensuing detailed description is directed thereto.

With respect to the first category of iontophoretic structure for a medical device, Fig. 1 illustrates an exemplary iontophoresis catheter 10 that uses the composite material approach to kill bacteria. The iontophoresis catheter 10 is substantially identical to a normal or non-infection controlling catheter in that it is a hollow flexible tube comprising an elastomeric wall 12 having an inner surface 14 and an outer surface 16, a proximal end 18, and a distal end 20. The generally cylindrical inner surface 14 defines a lumen 22 for the passage of fluid. Both the proximal end 18 and the distal end 20 are provided with one

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or more openings 26 to allow the fluid to be introduced or evacuated from the lumen 22. The distal end 20 is shaped to facilitate insertion or placement of the iontophoresis catheter 10 into the body. The iontophoresis catheter 10 may also be fitted with a retention device 28, such as a balloon fitting, to prevent unintentional withdrawal of the iontophoresis catheter 10 from the body.

Fig. 2 is a partial sectional view of the iontophoresis catheter 10 of Fig. 1, taken along the line A-A', that depicts details of a composite material comprising galvanic materials, such as metal powders, in a conductive elastomeric matrix 30 that distinguishes the iontophoresis catheter 10 from prior art catheters. The wall 12 of the catheter comprises the conductive base material 30, and a first and a second dissimilar metal powder, 32 and 34 respectively. The base material 30 is a conductive polymer similar to that used in static-proof bags for packaging charge-sensitive electronics in which the conductivity (resistivity) is controlled to a predetermined value by its composition. Exemplary conductive polymers can be made from polymers including polyvinyl, polyester, polyethylene, or a naturally conductive polyvinylidene fluoride. When loaded with carbon or other conductive fillers, for example, these polymers can be made conductive and thereby used as the base material 30 for an iontophoresis catheter 10. Exemplary first and second metal powder combinations having an electrochemical half-cell potential difference include silver and gold, silver and copper, or silver and platinum mixed into the polymer at very low volume concentrations prior to extrusion fabrication of the composite catheter 10. Although these exemplary powders are relatively expensive, they are used in such minute quantities that their use does not adversely impact overall cost of the iontophoresis catheter 10.

For catheter applications in which the elastomeric wall 12 is extruded, it is feasible to make the entire wall 12 from the composite material 30, 32, 34. However, Foley

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catheters which are typically made of latex and/or silicone rubber are not extruded, but are generally dip-cast, and finish-coating in a final dip is a natural processing step in their manufacture. Therefore, the iontophoresis catheter 10 can be made by finish-coating it with the composite material 30, 32, 34. Since rubber is generally inferior to plastic in terms of infection rates, overcoating with a castable plastic is advantageous in and of itself.

When the composite catheter 10 is placed in contact with or immersed in a fluid that is electrolytic, such as saline, blood, drug preparations, or urine, the first and second metal powders 32, 34 become an array of small batteries. Specifically, each powdered metal granule embedded in the base material 30 that makes contact with the electrolytic fluid 24 becomes either an anode or a cathode, depending on the particular metals chosen as the first and second metal powders 32, 34.

Referring to Fig. 3, a depiction of the iontophoresis effect created by the composite material 30, 32, 34 in the catheter of Fig. 2 is shown. The first and second metal powders 32, 34 act as electrodes and create a voltage potential therebetween, whereby electrons 36 migrate through the base material 30 and generate an electric current. Metal ions 38 are thus driven into the conductive fluid 24 by iontophoresis. The electric current is regulated by the quantity and nature of metal powder 32, 34 embedded in the base material 30 and by the conductivity of the base material 30. These factors are adjusted so that the current and ultimate metal ion densities are in an efficacious and safe range by use of the following formula:

$$I \left(\frac{\text{AMP}}{\text{CM}^2} \right) = \frac{V}{4r\rho} \ln \left[\frac{L^{-2/3}}{L^{-2/3}-1} \right]$$

wherein:

"I" is the total average current per unit surface area (amperes per cm²);

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" ρ " is the volume resistivity of the conductive base material 30 (ohm-cm);

"r" is the average metal powder granule radius (cm);

5 "V" is the voltage produced by the two dissimilar metals powders 32, 34 in the electrolytic fluid; and

"L" is the metal powder volume loading of the base material as a fraction (ie 0-1).

10 With respect to the above formula, the metal powders are assumed to be of the same granule size and of the same volume loading. In practice, they do not have to be the same size and volume loading. To achieve a current density between 10^{-8} to 10^{-6} Amperes per mm^2 , which is the desired range to be bacteriostatic or bactericidal and yet not be so high as to cause pH changes or other deleterious mammalian cell reactions, the following exemplary values can be used in the
15 above equation to define the composite material specifications:

V = 0.12 volts (for silver and gold in an NaCl electrolyte);

20 r = 10^{-3} cm;

ρ = 1.5×10^6 to 1.5×10^4 ohm-cm; and

L = 0.01.

An iontophoresis catheter 10 incorporating the above described composite material has numerous advantages over the
25 prior art with respect to effectiveness, controllability, and ease of use. Foremost, bacterial potency is maximized because metal is guaranteed to go into solution as ions, thus producing a minimum ten-fold reduction in bacterial colonization rate. Also, the iontophoresis catheter 10 does
30 not need an external current source or controller because the iontophoresis current is self-generating and self-regulating. Furthermore, because the metal powders 32, 34 (electrodes) are dispersed through the base material 30, and because the current level is very low, the electrodes are functional for
35 months of use. There is also no place in the circuit where corrosion of the electrodes at the air/electrolyte interface

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Fig. 10 depicts an alternative configuration of the iontophoresis catheter 70, wherein the plurality of layered structures 72 are bands that surround the wall 12. Alternatively, the layered structures 72 can be a plurality of longitudinal strips. The embodiments of Figs. 9 and 10 permit selective placement of a layered structure 72 on an isolated region of the wall 12, or distribution of the layered structures 72 on the entire wall 12.

Referring to Fig. 11, a partial cross section of the iontophoresis catheter 70 of Fig. 10 along the line B-B' is shown, wherein the layered structures 72 are bands adhered to the inner surface 14 and outer surface 16 of the wall 12. Each layered electrode 72 comprises a first metal electrode 76, a resistive layer 78, and a second metal electrode 80. As with the iontophoresis catheter 10 of Fig. 1, the metals are biocompatible and form an electrical potential difference between them in an electrolytic fluid. Whereas, in the iontophoresis catheter 10 of Fig. 1 the conductive (resistive) base material 30 regulates the current flow between the first and second metals 32, 34, in this embodiment the (conductive) resistive layer 78 regulates the current flow between the dissimilar metals of the first and second electrodes 76, 80.

For the iontophoresis catheter 70 of Figs. 9 and 10, wherein the first and second metal electrodes 76, 80 of the layered structures 72 have a 1 volt potential between them, a current density of 10^{-8} Amperes per mm^2 results if the thickness of the resistive layer 78 is approximately 10 micrometers and has a bulk conductivity of 10^{11} Ohm-cm and the exposed area of each of the electrodes 76, 80 in the layered structures 72 is the same. Typical combinations of metals used for the first and second metal electrodes 76, 80 generate between 0.1 to 2 Volts. Therefore, the thickness of the above described resistive layer 78 can be between 1 and 20 micrometers. Many other combinations of conductivity

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can cause the entire catheter to become non-functional with regard to its infection resistance. Finally, there is no change in procedure for placing or maintaining the iontophoresis catheter 10 because it is in many ways virtually identical to existing non-infection control devices in size and shape.

As previously discussed, the composite material approach finds ready application on numerous other medical devices where antibacterial properties are desirable. Fig. 4 is an illustration of the composite material 30, 32, 34 used to protect a pacing lead 40. The pacing lead 40 connects the heart tissue to the control and monitoring apparatus of a cardiac pacemaker (not shown) via a wire 42 and an electrode 44 in the tissue. The wire 42 is shown covered with the composite material 30, 32, 34. Fig. 5 is a depiction of the composite material 30, 32, 34 used with a prosthetic device, such as an artificial hip joint 46. The shaft 48 is shown coated with composite material 30, 32, 34 and implanted into a femur 50. Fig. 6A shows an infusion pump 52 coated with the composite material 30, 32, 34 and connected to tubing 54 which may also be coated.

The composite material 30, 32, 34 can also be coated onto a natural body structure 55, such as a tooth, as illustrated in Fig. 6B. This is accomplished by painting the composite material 30, 32, 34 onto the surface to be protected while the base material 30 is in a liquified or softened state and then letting the base material 30 harden. In an alternative embodiment the base material 30 is binary adhesive, such as a catalytic, two-part, conductive epoxy mix.

With further regard to catheters, a vascular access add-on device that benefits from the composite material approach for an iontophoretic structure is shown in Fig. 7, wherein an ordinary catheter 56 is shown fitted with an infection control kit 58 incorporating the composite material 30, 32, 34. The infection control kit 58 is an after-market device

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which includes a replaceable iontophoretic infection control sleeve 60 and an iontophoretic Luer adaptor 62 for connecting the proximal end 18 of the catheter 56 to intravenous (I.V.) tubing 64. The sleeve 60, made of or coated with the composite material 30, 32, 34 slips over the outer surface 16 of the catheter 56 to be inserted the body. The sleeve 60 covers only a short section of the catheter 56 near its proximal end 18, but is long enough to enter the body wherein moisture will activate the iontophoresis process. The sleeve 60 thus protects the catheter surface 16 from infection. The Luer adaptor 62 may also be made of or coated on the inner surface with the composite material 30, 32, 34 to protect the inner surface 14 of the catheter 56 from bacterial colonization progressing down to the catheter 56 from the inside of the I.V. tube 64. The sleeve 60 is fabricated from one of the above referenced conductive base materials 30; and the Luer adaptor 62 is made of a harder plastic, such as acrylic or polycarbonate. The sleeve 60 may be configured to accommodate a variety of catheter sizes.

An adaptation of the composite material sleeve 60 can also be configured as a catheter introducer sheath 66, shown in Fig. 8, for inserting pulmonary artery (Swan-Ganz or thermodilution) catheters, temporary pacing leads, etc., which may remain in place for several weeks. Under normal circumstances, an introducer sheath is left in place with the catheter which it surrounds for a portion of its length, including the region where the device penetrates the skin. Iontophoretic introducer sheaths 66 are easily manufactured with the composite material approach because they are predominantly made of polytetrafluorethylene (Teflon®), vinyl (PVC), or polyethylene (PE), materials which can be loaded with carbon or other conductive fillers or made conductive by other means known in the art and then loaded as well as the first and second metal powders 32, 34.

Fig. 8 shows the introducer sheath 66 used in conjunction with a thermodilution catheter 68. Balloon and

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temperature sensing elements, 74 and 75 respectively, known to those skilled in the art, are shown on the distal end 20. Because the inside of the introducer sheath 66 is in intimate contact with the outer surface 16 of the elastomeric wall 12, the composite material 30, 32, 34 of the introducer sheath 66 protects both the sheath 66 and the outer wall 12 of the thermodilution catheter 68. Like the iontophoresis catheter 10, and the catheter 56 having an iontophoresis infection control kit 58, the introducer sheath 66 is virtually identical in size, shape, and use as prior art devices.

As described with respect to Figs. 1-8, various embodiments of the composite material category of the iontophoretic structure for a medical device have been illustrated. In composite material embodiments, the integral power source for driving oligodynamic metal ions into solution is the electromotive force created by dissimilar metal powders 32, 34 embedded in and separated from each other by the conductive base material 30 of specifically created resistivity.

Referring now to Figs. 9-11, a variety of embodiments of the other category of iontophoretic structure for a medical device are shown which incorporate the plurality of discrete layered structures. In these embodiments a plurality of layered structures comprise dissimilar galvanic materials separated by a resistive layer. These structures may be incorporated in the above-recited medical devices during manufacture, or adhered to the surface of the devices as an aftermarket item.

Referring to Fig. 9 a perspective view of an embodiment of an iontophoresis catheter 70 is shown, wherein the oligodynamic iontophoresis effect is achieved using a plurality of layered structures 72 on either the inner surface 14, the outer surface 16, or both of a non-conductive wall 12. The layered structures 72, while depicted in a circular configuration can be any shape, such as oval or square.

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and thickness for the resistive layer 78 are possible to obtain the target current density.

5 Although the invention has been shown and described with respect to exemplary embodiments thereof, various other changes, omissions and additions in form and detail thereof may be made therein without departing from the spirit and scope of the invention.

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23. An iontophoresis catheter comprising:

an elastomeric cylindrical wall having an outer wall surface and an inner wall surface, said inner wall surface defining a lumen for containing an electrolytic fluid, and a distal end and a proximal end, each said end having at least one opening to permit introduction or evacuation of said electrolytic fluid from said lumen, said elastomeric cylindrical wall comprising a plurality of layered electrodes comprising a first metal layer, a second metal layer, and a resistive layer therebetween, said resistive layer having a predetermined resistance for controlling an electric current produced between said first metal layer and said second metal layer when said iontophoresis catheter is immersed in said electrolytic fluid to produce a desired current density that has an antibacterial effect.

24. An iontophoresis infection control kit for a catheter having a distal end, a proximal end, an inner lumen, and an outer surface, comprising:

an infection control sleeve comprising a first metal powder and a second metal powder embedded in a conductive elastomeric material having a predetermined resistance for controlling a current flow produced between said first metal powder and said second metal powder when said infection control sleeve is in contact with an electrolytic solution to produce a desired current density that has an antibacterial effect, said sleeve placed over said outer surface of said catheter near said proximal end.

25. The iontophoresis infection control kit of claim 24, wherein said infection control sleeve is an introducer sheath.

26. The iontophoresis infection control kit of claim 25, further comprising an adaptor for securing said infection control sleeve in place over said outer surface and for

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CLAIMS

I claim:

1. An iontophoretic structure for a medical device,
comprising:
 - 5 a first galvanic material having a first electrical potential;
 - a second galvanic material having a second electrical potential; and
 - 10 a conductive material separating said first galvanic material from said first galvanic material, said conductive material having a predetermined resistance for controlling a current flow produced between said first galvanic material and said second galvanic material when said iontophoretic structure is in contact with an electrolytic fluid.
- 15 2. The iontophoretic structure of claim 1, wherein said first galvanic material comprises silver and said second galvanic material comprises gold.
- 20 3. The iontophoretic structure of claim 1, wherein said first galvanic material comprises silver and said second galvanic material comprises platinum.
4. The iontophoretic structure of claim 1, wherein said first galvanic material comprises silver and said second galvanic material comprises copper.
- 25 5. The iontophoretic structure of claim 1, wherein said conductive material is a conductive polymer.
6. The iontophoretic structure of claim 5, wherein said conductive polymer is chosen from the group consisting of polyvinyl, polyester, polyethylene, polyurethane and polyvinylidene.

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18. The iontophoresis catheter of claim 9, wherein said first galvanic material comprises a first metal layer, said second galvanic material comprises a second metal layer, and said first and said second layers have a resistive layer therebetween, said first and second metal layers and said resistive layer comprising an antibacterial structure.

19. The iontophoresis catheter of claim 18, wherein said lumen comprises a plurality of said antibacterial structures on said outer wall surface.

20. The iontophoresis catheter of claim 19, wherein said lumen comprises a plurality of said antibacterial structures on said inner wall surface.

21. The iontophoresis catheter of claim 18, wherein said lumen comprises a plurality of said antibacterial structures on said inner wall surface and said outer wall surface.

22. An iontophoresis catheter comprising:

an elastomeric cylindrical wall having an outer wall surface and an inner wall surface, said inner wall surface defining a lumen for containing an electrolytic fluid, and a distal end and a proximal end, each said end having at least one opening to permit introduction or evacuation of said electrolytic fluid from said lumen, said elastomeric cylindrical wall comprising a first metal powder and a second metal powder embedded in a conductive material having a predetermined resistance for controlling a current flow produced between said first metal powder and said second metal powder when said iontophoresis catheter is contact with said electrolytic fluid to produce a desired current density that has an antibacterial effect.

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connecting said proximal end of said catheter to intravenous tubing.

27. A method of providing antibacterial protection for an implantable medical device comprising:

5 selecting a medical device having a surface that is exposed to bodily fluids when said medical device is implanted within a body;

 placing an iontophoretic structure on at least a portion of said surface, said iontophoretic structure including,

10 a first plurality of metal particles having a first galvanic electrical potential,

 a second plurality of metal particles having a second galvanic electrical potential, and

15 a non-conductive polymer loaded with a conductive material separating said first plurality of metal particles from said second plurality of metal particles, said conductive material providing said non-conductive polymer with a predetermined resistivity for controlling a current flow produced between said first plurality of metal particles
20 and said second plurality of metal particles when said iontophoretic structure is in contact with an electrolytic fluid; and

 implanting said medical device within said body.

28. A method of providing antibacterial protection for an implantable medical device comprising:

25 selecting a medical device having a surface that is exposed to bodily fluids when said medical device is implanted within a body;

30 placing an iontophoretic structure on at least a portion of said surface, said iontophoretic structure including,

 a first metal layer having a first galvanic electrical potential,

 a second metal layer having a second galvanic electrical potential, and

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a non-conductive polymer loaded with a conductive material separating said first metal layer from said second metal layer, said conductive material providing said non-conductive polymer with a predetermined resistivity for controlling a current flow produced between said first metal layer and said second metal layer when said iontophoretic structure is in contact with an electrolytic fluid; and implanting said medical device within said body.

29. A method of protecting a natural body structure with an iontophoretic structure including a first galvanic material having a first electrical potential, a second galvanic material having a second electrical potential, and a non-conductive polymer loaded with a conductive material separating said first galvanic material from said second galvanic material, said conductive material providing said non-conductive polymer with a predetermined resistivity for controlling a current flow produced between said first galvanic material and said second galvanic material when said iontophoretic structure is in contact with an electrolytic fluid, said first galvanic material including a first plurality of metal particles, said second galvanic material including a second plurality of metal particles, said first and said second plurality of metal particles embedded in said non-conductive polymer loaded with said conductive material, comprising the steps of:

applying said iontophoretic structure in a pre-cured state to said natural body structure; and
allowing said iontophoretic structure to cure.

30. The method of claim 29, wherein said non-conductive polymer loaded with a conductive material includes a binary adhesive.

31. The method of claim 29, wherein said body structure is a tooth.

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32. A method of providing antibacterial protection for an implantable medical device comprising:

selecting a medical device having a surface that is exposed to bodily fluids when said medical device is implanted within a body;

placing an iontophoretic structure on at least a portion of said surface, said iontophoretic structure including,

a first plurality of metal particles having a first galvanic electrical potential,

a second plurality of metal particles having a second galvanic electrical potential, and

an inherently conductive polymer separating said first plurality of metal particles from said second plurality of metal particles, said inherently conductive polymer having a predetermined resistivity for controlling a current flow produced between said first plurality of metal particles and said second plurality of metal particles when said iontophoretic structure is in contact with an electrolytic fluid; and

implanting said medical device within said body.

33. A method of protecting a natural body structure with an iontophoretic structure including a first galvanic material having a first electrical potential, a second galvanic material having a second electrical potential, and an inherently conductive polymer separating said first galvanic material from said second galvanic material, said inherently conductive polymer having a predetermined resistivity for controlling a current flow produced between said first galvanic material and said second galvanic material when said iontophoretic structure is in contact with an electrolytic fluid, said first galvanic material including a first plurality of metal particles, said second galvanic material including a second plurality of metal particles, said first

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and said second plurality of metal particles embedded in said inherently conductive polymer, comprising the steps of:

applying said iontophoretic structure in a pre-cured state to said natural body structure; and

5 allowing said iontophoretic structure to cure.

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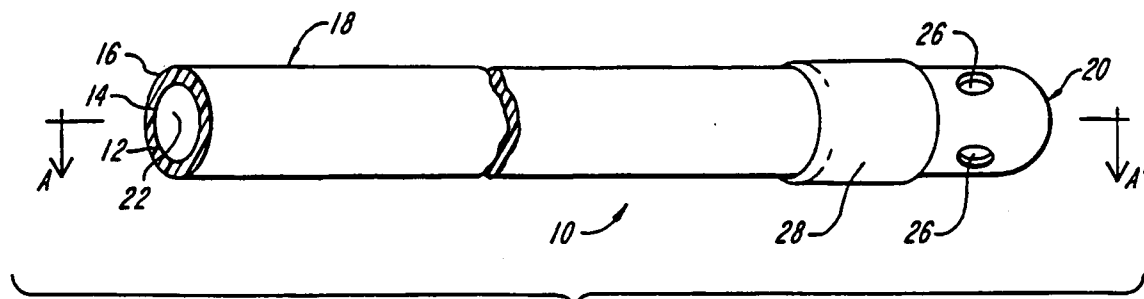


FIG. 1

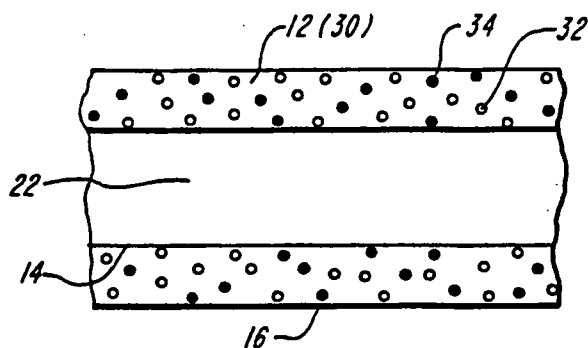


FIG. 2

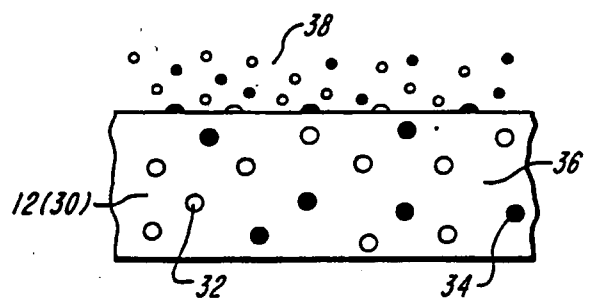


FIG. 3

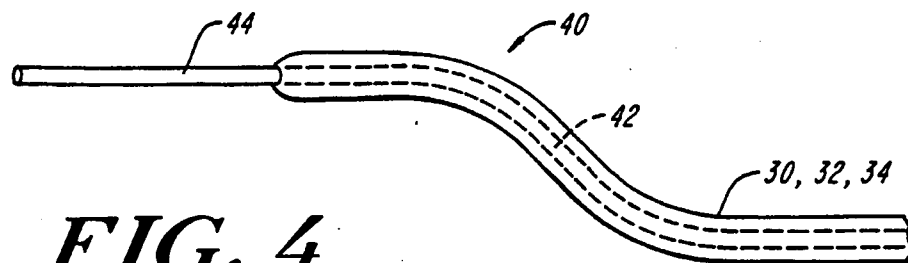


FIG. 4

SUBSTITUTE SHEET

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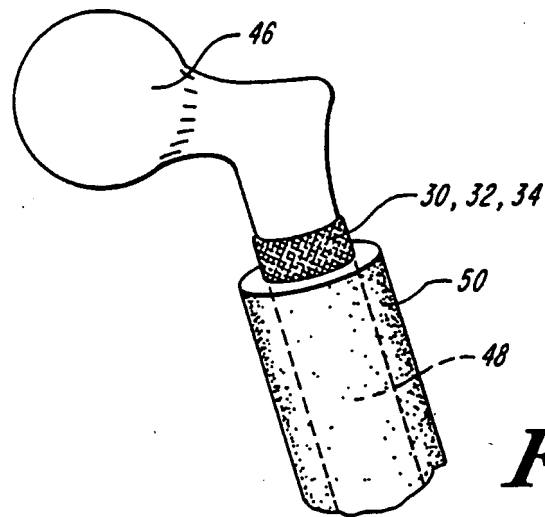


FIG. 5

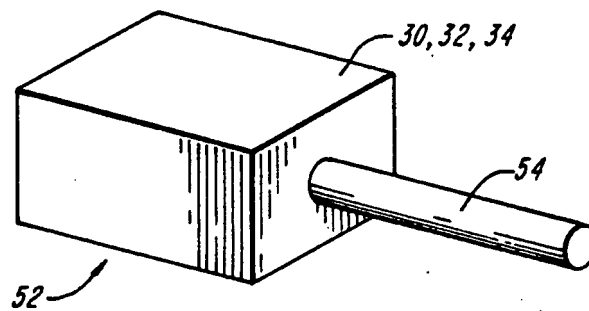


FIG. 6A

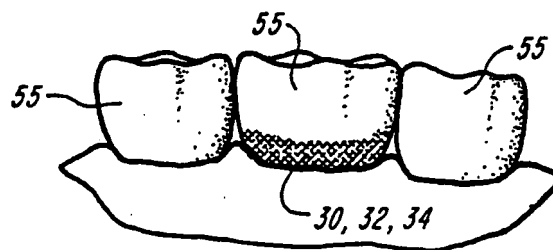


FIG. 6B

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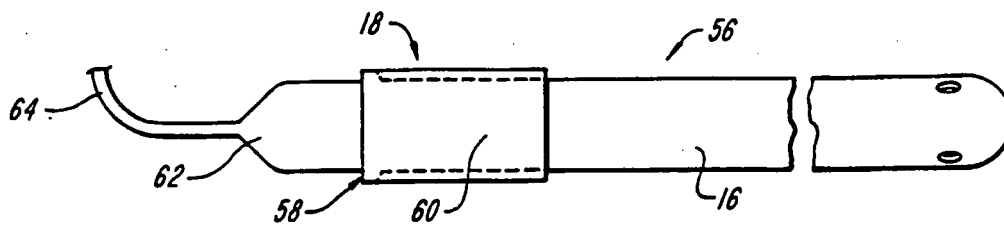


FIG. 7

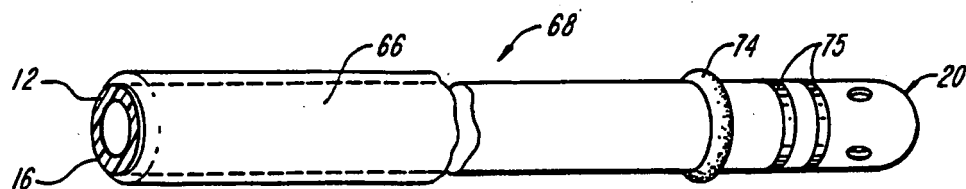


FIG. 8

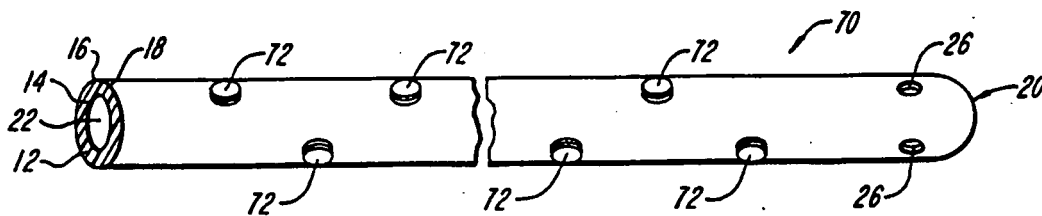


FIG. 9

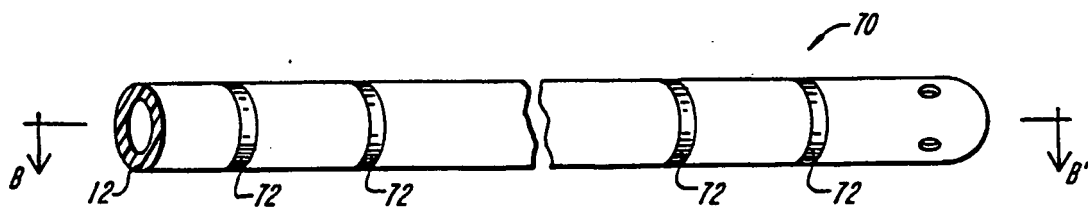


FIG. 10

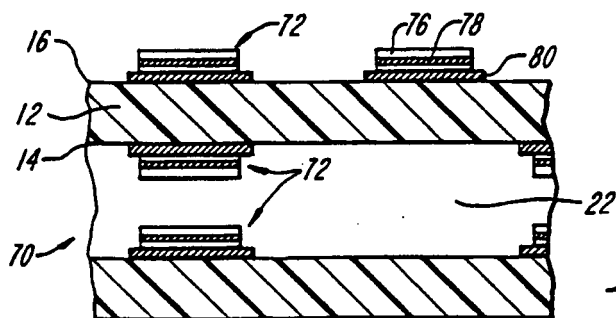
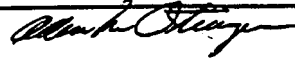


FIG. 11

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INTERNATIONAL SEARCH REPORT

In. ational application No.
PCT/US93/10911

A. CLASSIFICATION OF SUBJECT MATTER IPC(5) :A61N 1/30 US CL :604/20; 604/265 According to International Patent Classification (IPC) or to both national classification and IPC																				
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) U.S. : 604/8, 20, 21, 27, 173, 192, 265, 266, 280; 607/122, 149, 152, 153; 128/389, 391, 642, 783, 786 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched None Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) None																				
C. DOCUMENTS CONSIDERED TO BE RELEVANT																				
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.																		
Y	EP, A, 0,206,024 (HAYNES ET AL.) 30 December 1986. See entire document.	1-23, 27, 28 , and 32																		
Y	US, A, 4,886,075 (JONES) 12 December 1989. See entire document.	29-31, 33																		
A	US, A, ^{4,313,438} (GREATBATCH), 02 February 1982. See entire document.	29-31, 33																		
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.																				
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O document referring to an oral disclosure, use, exhibition or other means																				
P document published prior to the international filing date but later than the priority date claimed																				
Date of the actual completion of the international search 11 JANUARY 1994		Date of mailing of the international search report 25 APR 1994																		
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. NOT APPLICABLE		Authorized officer  Vanitha Alexander Telephone No. (703) 308-4987																		

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/10911

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

I. Claims 1-26, drawn to an iontophoretic structure for a medical device, classified in Class 604, subclass 265.

II. Claims 27-33, drawn to methods of providing antibacterial protection for implantable devices and natural body structures classified in Class 604, subclass 20.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

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